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On the Relation Between the Stiles–Crawford Effect and Its Optical Equivalent

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Abstract

Purpose: The Stiles–Crawford Effect (SCE), that makes the visual sensitivity dependent on exact pupil location of an incident beam, and its optical equivalent, the Optical SCE (OSCE), manifested by a directional component of light reflected back from the retina, can be explained by the waveguide properties of photoreceptors. However, there is a commonly–observed difference by a factor of two of the directionality parameter measured with the two techniques at the fovea. We propose a photoreceptor–to–light coupling model to explain the directionality parameters normally observed in both the SCE and the OSCE.

Methods: The photoreceptors are modeled as weakly–guiding optical fibers and we study their coupling to an incident field that may either be a plane wave or a focused beam as used in a scanning laser ophthalmoscope. We included in the model an important novel feature: diffraction in the reduced eye model that directly leads to a relation between pupil field and retinal light distribution both for the incoming and the back–reflected light. From this relation, together with the coupling strength, directionality parameters for the SCE and the OSCE are derived and held in relation to the waveguide properties of an individual receptor.

Results: For foveal receptors with a typical diameter of 2.5 µm we find directional parameters of $0.048/mm^2$ (SCE) and $0.102/mm^2$ (OSCE) at a wavelength of 543 nm, in excellent agreement with values reported in the literature. Both values are found to increase with distance from the center of the fovea (and thus with receptor width) and to be inverse proportional with the square of the illumination wavelength due to diffraction in the eye. The relations were derived under the assumption that although the incident light may excite various modes to produce the SCE, the back–reflected light is dominated by the fundamental quasi–Gaussian mode that cause the peak in directionality observed with the OSCE. The model also reproduces the larger OSCE directionality parameter observed with systems based on dual aperture scanning.

Conclusions: A model of photoreceptor–to–light coupling together with diffraction may suffice to explain the reported directionality parameters observed with both the SCE and the OSCE. The model reproduces well measured values both at and off the fovea, as well as the overall wavelength dependence. This modeling will be useful to gain further insight into photoreceptor waveguide parameters such as inner diameter and orientation in the real living eye, and eventually in the design of new retinal/photoreceptor imaging instruments.

Keywords: photoreceptors • computational modeling • retina